A scheme for quantum communication using EPR pairs and local measurement

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We present a scheme for quantum communication, where a set of EPR pairs, initially shared by the sender Alice and the receiver Bob, functions as a quantum channel. After insuring the safety of the quantum channel, Alice applies local measurement on her particles of the EPR pairs and informs Bob the encoding classical information publicly. According to Alice's classical information and his measurement outcomes on the EPR pairs Bob can infer the secret messages directly. In this scheme, to transmit one bit secret message, the sender Alice only needs to send one bit classical information to the receiver Bob. We also show that this scheme is completely secure if perfect quantum channel is used.

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I. INTRODUCTION

Cryptography is the art of enabling two parties to communicate in private. It plays an increasing important role in the whole world. Before transmitting their secret messages the two distant parties must distribute secret key first. As it is unsafe to distribute secret key through a classical channel, people have paid a lot of attention to quantum key distribution, the most advanced application of the principles of quantum mechanics such as the uncertainty principle and quantum correlations. Quantum key distribution or quantum cryptography provides a secure way for two remote parties, say Alice and Bob, to create a randomly binary string that can be used as a secret key with which they can communicate securely using Vernam one-time pad crypto-system. In 1984, Bennett and Brassard presented the first quantum cryptography, BB84 protocol [1]. Ekert proposed another quantum key distribution scheme depending on the correlation of Einstein-Podolsky-Rosen (EPR) pair, the maximally entangled state of two particles in 1991 [2]. Afterward Bennett also put forward a quantum cryptography scheme known as B92 protocol [3]. Up to now, there have already been a lot of works in quantum key distribution on both theoretical and experimental aspects [4 - 18].

Recently, novel quantum secure direct communication protocols were proposed by Shimizu and Imoto [19, 20] and Beige et al. [21]. In these protocols, the two parties communicate important messages directly without first establishing a shared secret key to encrypt them and the messages are deterministically sent through the quantum channel, but can only be decoded after a final transmission of classical information. A direct communication scheme, the "ping pong protocol" which is insecure if it is operated in a noisy quantum channel, as indicated by Wójcik [22], was put forward by Boström and Felbinger [23]. More recently Deng et al. gave a two-step quantum direct communication scheme using EPR pair block [24] and a secure direct communication protocol with a quantum one-time-pad [25]. However, in all these secure direct communication schemes it is necessary to send the qubits with secret messages in the public channel. Therefore a potential eavesdropper, Eve, can attack the qubits in transmission. In order to prevent the qubits transmitted in the public channel, we suggested a scheme for secure direct communication between Alice and Bob, using EPR pairs and teleportation [26], and two quantum secure direct communication protocols, one by EPR pairs and entanglement swapping [27] and the other with GHZ states and entanglement swapping [28]. Gao et al. provided two schemes for controlled and secure direct communication using three-particle entangled state and teleportation [29, 30]. Since there is not a transmission of the qubits carrying the secret messages between two communication parties in the public channel, they are secure for direct secret communication if perfect quantum channel is used. In the protocol of Ref. [26], for transmitting one bit secret message, Alice have to send two bits classical information to Bob, because the Bell measurement would produce four random outcomes, so it would waste the classical information resource.

In this paper, we would like to improve the quantum communication scheme stated in Ref. [26] and give a simpler but more economical one. In the new quantum communication scheme Alice only requires to send one bit classical information to Bob for her to transmit one bit secret message.

II. SCHEME FOR QUANTUM COMMUNICATION

We suppose that the two communication parties Alice and Bob share a set of EPR pairs, the maximally entangled pair in the Bell state

$$|\Phi^+\rangle_{AB} = \frac{1}{\sqrt{2}}(|00\rangle_{AB} + |11\rangle_{AB}). \qquad (1)$$

As a matter of fact, there are many different ways for Alice and Bob to obtain these EPR pairs. For instance, Alice makes the pairs first then sends half of each to Bob. Or a sever could prepare the pairs and then send half of each to Alice and Bob. In order to make sure of the purity of EPR pairs, Alice and Bob must do some tests. They can use the schemes testing the security of EPR pairs (quantum channel) in Refs.[2, 4, 13, 24, 26]. Passing the test insures that they continue to hold sufficiently pure, entangled quantum states. However, if tampering has occurred, they discard these EPR pairs and construct new EPR pairs again.

In virtue of these pure EPR pairs, Alice and Bob can start their quantum communication. Suppose that Alice wishes to communicate to Bob. First Alice makes the local measurement on her particle A in the basis $\{|0\rangle_A, |1\rangle_A\}$. Alice and Bob agree on that if Alice's measurement outcome is the same with the secret message to be transmitted, then Alice sends classical information 0 to Bob, otherwise she sends classical information 1 to Bob. For example, if Alice wants to send Bob secret message 0100100 and Alice's measurement outcomes on the seven EPR pairs are the states $|0\rangle, |1\rangle, |1\rangle, |0\rangle, |0\rangle, |0\rangle, |1\rangle$, then Alice transfers the classical information 0010101 via classical public channel to Bob. Bob applies local measurement on his qubits B of the EPR pairs in the basis $\{|0\rangle_B, |1\rangle_B\}$. Clearly, he must obtain the same results $|0\rangle, |1\rangle, |1\rangle, |0\rangle, |0\rangle, |0\rangle, |1\rangle$ as Alice. According to his measurement results and the classical information he received, Bob can infer the secret message 0100100 that Alice wants to transmit to him.

It is clear that in our scheme the classical information resource is saved on since one bit classical information is only wanted to transmit one bit secret message.

Evidently, the security of this protocol is only determined by the quantum channel. In fact a perfect quantum channel can be achieved by using the schemes testing the security of EPR pairs. Therefore this scheme for quantum communication using EPR pairs and local measurement is absolutely reliable, deterministic and secure.

As mentioned in Ref. [26], Eve can obtain information if the quantum channel is not the perfect EPR pairs.

For example if Eve couples EPR pair with her probe in preparing EPR pair, and makes the quantum channel in the following entangled state

$$|\Psi\rangle_{ABE} = \frac{1}{\sqrt{2}}(|000\rangle_{ABE} + |111\rangle_{ABE}), \qquad (2)$$

then she is in the same position with the legitimate party Bob. But this case can be ruled out after Alice and Bob check the EPR pairs by means of their local measurement in the basis $\{|0\rangle, |1\rangle\}$ or basis $\{\frac{1}{\sqrt{2}}(|0\rangle+|1\rangle), \frac{1}{\sqrt{2}}(|0\rangle-|1\rangle)\}$ randomly and comparing their measurement results as stated in Ref. [26]. If Eve uses so called entanglement pair method to obtain information, she will also be found by Alice and Bob's test, which was shown in Ref. [26]. So in any case, as long as an eavesdropper exists, she will be found and we can realize secure quantum communication.

III. SUMMARY

We give a scheme for quantum communication. The communication is based on EPR pairs functioning as quantum channel and local measurement. After insuring the safety of the quantum channel, Alice and Bob apply local measurement on the EPR pairs and Alice broadcasts encoding classical information publicly. According to the broadcast classical information and his measurement outcomes on the EPR pairs Bob can infer the secret messages directly. On one hand, transmitting one bit secret message only needs transmitting one bit classical information, on the other hand, there is not a transmission of the qubit which carries the secret message between Alice and Bob, neither the communication can be interrupted by Eve, nor the secret information is leaked to Eve. Therefore our new protocol has high capacity and defends signal against interference.

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[1] C. H. Bennett and G. Brassard, Proc. IEEE Int. Conf. on Computers, Systems and Signal Processing, Bangalore, India, (IEEE, New York, 1984), pp. 175-179.
[2] A. K. Ekert, Phys. Rev. Lett. **67**, 661 (1991).
[3] C. H. Bennett, Phys. Rev. Lett. **68**, 3121 (1992).
[4] C. H. Bennett, G. Brassard, and N. D. Mermin, Phys. Rev. Lett. **68**, 557 (1992).
[5] C. H. Bennett and S. J. Wiesner, Phys. Rev. Lett. **69**, 2881 (1992).
[6] L. Goldenberg and L. Vaidman, Phys. Rev. Lett. **75**, 1239 (1995).
[7] B. Huttner, N. Imoto, N. Gisin, and T. Mor, Phys. Rev. A **51**, 1863 (1995).
[8] M. Koashi and N. Imoto, Phys. Rev. Lett. **79**, 2383 (1997).
[9] D. Bruß, Phys. Rev. Lett. **81**, 3018 (1998).
[10] W. Y. Hwang, I. G. Koh, and Y. D. Han, Phys. Lett. A **244**, 489 (1998).
[11] A. Cabello, Phys. Rev. Lett. **85**, 5635 (2000).
[12] A. Cabello, Phys. Rev. A **61**, 052312 (2000).
[13] G. L. Long and X. S. Liu, Phys. Rev. A **65**, 032302 (2002).
[14] P. Xue, C. F. Li, and G. C. Guo, Phys. Rev. A **65**, 022317 (2002).

[15] S. J. D. Phoenix, S. M. Barnett, P. D. Townsend, and K. J. Blow, J. Modern Optics **42**, 1155 (1995).
[16] D. Song, Phys. Rev. A **69**, 034301 (2004).
[17] X. B. Wang, Phys. Rev. Lett. **92**, 077902 (2004).
[18] M. Hillery, V. Bužek, and A. Berthiaume, Phys. Rev. A **59**, 1829 (1999).
[19] K. Shimizu and N. Imoto, Phys. Rev. A **60**, 157 (1999).
[20] K. Shimizu and N. Imoto, Phys. Rev. A **62**, 054303 (2000).
[21] A. Beige *et al*, Acta Phys. Pol. A **101**, 357 (2002).
[22] A. Wójcik, Phys. Rev. Lett. **90**, 157901 (2003).
[23] K. Boström and T. Felbinger, Phys. Rev. Lett. **89**, 187902 (2002).
[24] F. G. Deng, G. L. Long, and X. S. Liu, Phys. Rev. A **68**, 042317 (2003).
[25] F. G. Deng and G. L. Long, Phys. Rev. A **69**, 052319 (2004).
[26] F. L. Yan and X. Q. Zhang, Euro. Phys. J. B **41**, 75 (2004).
[27] T. Gao, F. L. Yan, and Z. X. Wang, arXiv: quant-ph/0406082
[28] T. Gao, F. L. Yan, and Z. X. Wang, Nuovo Cimento B **119**, 313 (2004).
[29] T. Gao, Z. Naturforsch **59a**, 597 (2004).
[30] T. Gao, F. L. Yan, and Z. X. Wang, arXiv: quant-ph/0403155